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Maturity-based approach for the development of environmentally sustainable product/service-systems

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Abstract

Despite their substantial potential for enabling increased environmental performance, product/service-systems (PSS) are not intrinsically environmentally sustainable. In order to ensure increased environmental performance, PSS best practices should be integrated with ecodesign best practices, from the early stages of the development process. This paper aims to identify the best practices for PSS development, based on a systematic literature review, and to propose their integration into an existing maturity model for ecodesign, the EcoM2, into which 30 best practices for PSS development are identified and integrated. The proposed approach has the potential to enable the development of environmentally sustainable PSS offerings.

Keywords: environmental sustainability, maturity model, best practices, product/service-systems, ecodesign

1. Introduction

The current industrial shift from selling products to providing product/service-systems (PSS) is mainly driven by business motivations [1]–[4]. Increased competitiveness, reduced costs, enhanced customer convenience and flexibility, and improved corporate identity [5], [6] are some of the business drivers towards PSS.

In addition to potential economic benefits, PSS is also seen as a feasible and promising environmental strategy, with the potential of enabling a more sustainable society through the provision of solutions with improved environmental performance [7], [8]. In a PSS context, the service provider is often stimulated to use and maintain any related products properly, increasing both efficiency and effectiveness, which leads to several potential environmental benefits [6], [9], [10], such as:

- Lower materials and energy consumption during production and use;
- Extension of the manufacturer's responsibility for the product in the use and end-of-life phases;
- Development of more durable and use-intensive products;
- Higher quality end-stock and less down-cycling;
- Optimisation of products to their primary function(s), with better insight into the product requirements;
- Collection of end-of-life products, with increased re-use;
- Easier upgrading to more eco-efficient technologies.

PSS has the potential to break the link between production volume and profit, enabling a reduction of resource consumption, increased motivation to deal with through-life and end-of-life issues as the manufacturer retains ownership of assets, enhanced in-use efficiency, product longevity/durability, and effective reuse of materials [11], [12].

Despite the potential of PSS to enable the creation of more sustainable systems, the mere addition of services to conventional products does not necessarily lead to a reduction of environmental impacts [13]–[17]. The development of PSS is not intrinsically sustainable and there are cases in which the environmental impacts are higher, when compared to traditional product systems [9], [12], [18], [19]. The PSS environmental performance depends on the product and systems' design and on the efficiency of the networks and infrastructure within which the PSS is operated [16], [20].

The PSS design process is therefore one of the most influential factors in the development of sustainable PSS [13], [21]. Structured practices for PSS development are needed to enable each process phase to transform the inputs to valuable outputs and to manage the interaction with the different actors throughout the system life cycle [22]. It is essential that considerations of environmental sustainability are integrated into the PSS design and development process, that its market launch is carefully prepared to ensure success, and that the PSS solution on the market is constantly reviewed in terms of economic, environmental and social impacts [23]. In summary, the implementation of ecodesign best practices into the PSS development process has the potential to increase the environmental performance of the developed PSS, supporting the transition towards a more sustainable system [24].

This paper aims to identify the best practices for PSS development, based on a systematic literature review, and to propose their integration into the Ecodesign Maturity Model (EcoM2), a maturity-based framework developed to support companies in the integration of ecodesign best practices into product development and related processes. The main result presented in the paper is a maturity-based approach to support companies in the development of PSS with increased environmentally sustainable performance.

The following section provides a description of the EcoM2, the maturity-based approach employed in this research to support the development of environmentally sustainable PSS. Section 3 presents the methodology employed for the identification of the best practices for PSS development and their subsequent integration into the EcoM2. Section 4 presents the identified best practices for PSS development. Section 5 presents the integration of the identified best practices for PSS development into the EcoM2, and is followed by conclusions and final remarks (section 6).

2. Ecodesign Maturity Model

The Ecodesign Maturity Model (EcoM2) is a framework that supports manufacturing companies to achieve systematic and consistent implementation and management of ecodesign [25] in the product development and related processes (such as strategic planning, marketing and manufacturing).

The EcoM2 focuses on improving the integration of environmental issues into the decision-making processes, by enhancing the capabilities of companies to develop products with increased environmental performance, across their entire portfolio. It is composed of three main components [25]: maturity levels; body of knowledge of best practices; and application method.

Five maturity levels in the EcoM2 are defined to support companies in implementing ecodesign by the combination of evolution levels (described in section 3) and capability levels [25]. The maturity levels establish the path for ecodesign implementation, from the most simple and basic practices that will create the foundation for ecodesign implementation, to the most advanced and complex ones.

The body of knowledge of best practices contains hundreds of best practices for ecodesign implementation and management in the strategic, tactical and operational levels. The best practices are classified into management practices, operational practices and methods & tools [26], which are interrelated among them and classified according to several criteria to support their selection.

Finally, the application method defines a PDCA (plan-do-check-act) approach in six steps to support companies to improve their maturity profile over time. The six steps are: 1) diagnosis of the current maturity profile; 2) definition of a vision of desired maturity; 3) deployment of a strategic roadmap for ecodesign implementation; 4) planning of the improvement projects; 5) implementation and change management; 6) monitoring and evaluation of the improvement projects. The improvement cycles can be carried out as many times as needed to keep enhancing companies' maturity based on their strategic drivers and goals.

The EcoM2 has been validated in a number of studies, where several manufacturing companies have implemented the approach, to increase the effects of their efforts with ecodesign [27], [28]. The results of the application corroborate the hypothesis that the model can support companies in prioritizing actions for a consistent and systematic ecodesign implementation – providing them the direction and best practices to be implemented.

In its initial development and testing, the EcoM2 was built on the body of knowledge from the field of ecodesign. As such, this field had some connections to PSS, but did not include a specific search for PSS development. Since the EcoM2 has been built and validated in industry, the research field and industrial application of PSS has advanced greatly – both from an environmental and a non-environmental viewpoint. These developments are not reflected in the original version of the EcoM2, which is why this study focuses to include PSS support from an environmentally enhanced perspective.

3. Methodology

The methodology employed for the identification of best practices for PSS development and their integration into the EcoM2 consisted of two main steps, as presented in the following sub-sessions.

3.1. Systematic Literature Review for the identification of best practices for PSS development

In this research, previous literature review studies performed to identify best practices for PSS development [29] were complemented with a systematic literature review. Systematic literature reviews follow a well-defined sequence of methodological steps according to a previously developed review protocol [30], [31]. The systematic review model followed in this research comprised three phases, namely: (1) planning, (2) execution, and (3) analysis of the results [31].

The planning phase consisted in the definition of the review protocol, which contains problem formulation, data collection and evaluation strategies, results analysis and communication strategy. The databases, keywords and logical research terms used in the systematic literature review were defined according to the study's objectives, i.e. to identify the best practices for PSS development. The database selected in this review is the ISI Web of Science, due to its comprehensiveness in the focus area of the researched knowledge area. The selection of keywords and logical terms was performed iteratively. To begin with, the keywords were extracted from a set of 27 scientific papers, which were considered in previous studies for the identification of PSS best practices [29]. As the review proceeded, new keywords emerged and were added to the initial set, resulting in new searches in the database using the newly included keywords. The consolidated search string adopted in this research, defined based on a combination of a set of synonymous for "PSS" and "best practices" is defined as (("product/service-system" OR "PSS" OR "servitization" OR "integrated product service") AND ("practice" OR "tools" OR "success factors" OR "method" OR "framework" OR "approach or guideline")). Servitization was added as a keyword due to the fact that PSS is often implemented by manufacturing companies by means of servitization [32]–[36].

Sustainability-related keywords were not included in the string, since best practices aiming at development PSS with increased environmental performance are a subset of PSS best practices and would, therefore, be identified by means of the defined string. The search was refined to include only articles in English and from the following knowledge areas: engineering, environmental sciences ecology, business economics, materials science and behavioural science. The knowledge areas were selected to enable a more focused and relevant literature review, and their consistency was checked in order to avoid significant flaws. Nevertheless, other knowledge areas could also prove to be relevant and must be explored in future reviews.

Due to the emerging characteristic of the PSS research field, both journal papers and conference papers were considered in this review. The studies to be included in the scope of the review were selected by applying the inclusion/exclusion criteria. The selected studies were the ones that presented best practices for PSS development, by means of models, frameworks, guidelines, case studies, literature reviews, etc. The procedure for selecting studies using the inclusion/exclusion criteria was a reading of their title and abstracts. Whenever this reading proved insufficient to include or exclude a study, the entire article was analysed and a decision was taken.

The execution phase was performed based on the review protocol, defined in the planning phase. The identification of studies was carried out in July-October 2015 and resulted in a set of 71 scientific studies. Applying the inclusion/exclusion criteria, 43 studies that present best practices for PSS development (either directly or indirectly) were selected and analysed for the identification of the PSS best practices. Most of the selected papers are conference papers, which reinforces the hypothesis of the emerging characteristic of PSS as a research field.

The best practices for PSS development (presented in section 4) were extracted from the selected papers, by identifying the necessary activities and tasks to be performed by manufacturing companies, in order to be able to develop PSS considering a broad range of aspects, such as business models, marketing, design and development, network management, value creation, servitization strategies, etc. Generalizations of the best practices were performed, in order to consolidate similar practices. In total, 30 best practices for the development of PSS, from a managerial perspective, were identified. This research focused on the identification of management best practices for PSS development. Operational practices and methods & tools were not included in the scope of this research.

3.2. Integration of the identified best practices for PSS development into the EcoM2 and customization of the EcoM2 best practices for PSS development

The 30 identified best practices for PSS development were fully integrated into the EcoM2 by performing their classification in relation to the EcoM2 evolution levels (Table 1), which were adapted for the development of environmentally sustainable PSS.

Table 1. Evolution Levels defined by the EcoM2 [adapted from 14]

Evolution level	Description
Level 1	Limited experience in the development of environmentally sustainable PSS, focus on elementary understanding of the concept, external and internal drivers, context and barriers
Level 2	Start-up of pilot projects for the implementation of PSS, by changing business models and organizational structures
Level 3	Experience gained in the pilot projects supports the systematic integration of environmental considerations into the PSS development and related processes
Level 4	Expansion of the ecodesign implementation to managerial and business areas, in addition to the technical areas.
Level 5	Incorporation of environmental issues into the corporate, business and product strategies – environment is integrated in the decision making processes and into the business

The five evolution levels describe how a company evolves in its integration of environmental issues into PSS development [adapted from 14]. The evolution levels range from a focus on elementary understanding of external and internal drivers, context, barriers, and contextual background all the way up to the incorporation of environmental issues into the strategic decision making processes and into the way in which the company does business. The classification of the 30 identified best practices for PSS development according to the five evolution levels was carried out by evaluating the order of implementation of the practices (from the ones that will create the basis and foundation for implementation to the most advanced ones) and by considering their interdependencies. It does not mean that the practices in the first evolution levels are necessarily easier to implement, but that they should be implemented first in order to create the foundation for the others. After the initial classification, an evaluation based on existing frameworks for PSS development was performed and complemented by an internal expert evaluation.

Furthermore, in order to support the application of the best practices for PSS development in a product development context, the practices were classified according to the group of activities of a reference model for the product development process [37], [38] (Table 2), based on a cross-content analysis. The decision to adopt a reference model for product development instead of a reference model for PSS development was based on the fact that most of the manufacturing companies will implement PSS by means of a servitization process, which implies that the PSS implementation will be built upon their current product development processes and procedures.

Table 2. Phases and main activities of the reference model for product development adopted in the EcoM2 [37], [38]

Phases for product development	Main activities
Product strategic planning (PSP)	Define the business strategic plan; consolidate information about technology and market; analyse and refine the portfolio of products
Informational design (IDE)	Revise and update the product's scope; detail the product life cycle and define the main customers/users; identify customers' and product's requirements
Concept design (CDE)	Model the product functions; develop solution principles and alternative solutions; define product architecture; analyse systems, sub-systems and components; define ergonomics and aesthetics; define suppliers and partners for co-development; select product concept
Detailed design (DDE)	Detail the design of systems, sub-systems and components; make or buy decisions; develop suppliers; plan manufacturing and assembly processes; optimize product and process; create support material; develop packaging; plan end-of-life; product test and homologation; share product documentation
Production preparation (PPR)	Gather manufacturing resources; plan pilot production; produce pilot lot; process homologation; optimize production; certificate product; develop production and maintenance process; transfer knowledge
Product launch (PLA)	Develop sales process; develop distribution process; develop customer support services; develop technical assistance processes; promote launch and marketing; launch the product; manage the product launch
Product accompanying and monitoring (PAM)	Evaluate customers' satisfaction; monitor the product performance (technical, economic, production, services, etc.)

Although the development process may vary between different companies and product types, the generic design process (i.e. high-level reference models) can be used to tailor the specific ecodesign procedures [37], [38]. The results of the integration into the EcoM2, presented in section 4, allow the prioritization of practices following the maturity profile of the companies and their strategic drivers. In addition to the phases of the reference model, the best practices for PSS development were also classified in regards to change management practices (CMP).

Subsequently, the existing 62 management practices of the EcoM2 for ecodesign implementation were customized and adapted for a PSS development context, in opposition to a product development context. Grounded theory and contextual analysis techniques were employed in the adaptation.

The ecodesign and PSS practices were then consolidated and harmonized, guaranteeing a joint application by manufacturing companies for the development of environmentally sustainable PSS. Similar practices were integrated into a single practice, aiming to guarantee consistency in the so-called EcoM2 for

PSS model. As a result of this three-step integration, the consolidated EcoM2 for PSS contains a total amount of 88 best practices for the development of environmentally sustainable PSS.

The results of the integration of PSS best practices into the EcoM2, presented in section 5, allow the prioritization of practices based on the application method, following the maturity profile of the companies and their strategic drivers.

4. Best practices for PSS development

This research focused on the identification of the best practices for PSS design and development dealing with the managerial activities required to develop a PSS. Best practices are defined as an optimal way currently recognized by industry to achieve a stated goal or objective [39].

The identified best practices for PSS development are presented in table 3. Whenever necessary, similar practices were clustered in a unique practice, so to simplify the set of practices and ensure consistency and robustness. The practices are coded to simplify cross-citation and presented together with the main references to allow traceability. The first 17 best practices (BP1-17) were presented in a preliminary study developed by the authors, which is the foundation for this paper [29]. By means of the systematic literature review carried out in this research, the relevance of the previously identified best practices was reinforced by additional references, and 13 new best practices were identified.

Table 3. Best practices (BP) for PSS development

Code	Best practice	References
BP1	Develop a business model that can support the transition towards PSS	[1], [3], [12], [40]–[44]
BP2	Create actor networks that foster innovation and promote customer resource integration	[2], [3], [14], [21], [40], [41], [44]–[50]
BP3	Define PSS offerings and value propositions to be provided to customers and stakeholders based on their needs	[3], [8], [41], [48], [49], [51]–[54]
BP4	Add service elements to the portfolio of offerings	[40], [41], [48], [55], [56]
BP5	Understand customer value creation processes to develop suited and specific value propositions	[4], [14], [40], [41], [44], [46], [48], [57]–[60]
BP6	Co-create value together with the customers by developing service- and customer-oriented offerings	[1]–[4], [14], [15], [41], [55]
BP7	Identify available offerings in the market	[41], [56]
BP8	Understand the life cycle of the offerings	[40], [46], [48], [50], [54], [55], [61]
BP9	Map and visualize the actual activities of the users of the company's offerings	[3], [48], [55], [58], [62]
BP10	Focus on value-driven communication of offerings – clearly communicate the value associated with the PSS offer	[12], [14], [59], [60]
BP11	Increase the extent of interactions with customers through the PSS offerings	[14], [40]
BP12	Collect PSS data through increased interaction with customers	[2], [12], [14], [55], [58], [59], [63], [64]

BP13	Align physical product characteristics with service offer characteristics and vice-versa	[14], [50], [54], [65]–[67]
BP14	Identify preferable product properties to increase the value of the PSS business model	[14], [60], [65], [68]
BP15	Define the level of customization of the PSS offering according to the business model	[14], [40], [69]
BP16	Assess strengths and weaknesses of the current product portfolio and markets	[12]
BP17	Identify the market value of the PSS compared to the competing product in terms of tangible and intangible value	[12], [51], [60]
BP18	Develop service-oriented capabilities in corporate culture, human resource management, and organization structures	[2], [70]
BP19	Strategic couple the manufacturing system and the service system	[53], [66], [70]
BP20	Develop a service-driven strategy	[3]
BP21	Search for value proposition opportunities throughout the entire product life cycle	[3], [49], [71]
BP22	Plan the PSS implementation and operation processes for service delivery based on expected consumer behaviour	[16], [53], [54], [72]
BP23	Identify customers and stakeholders' requirements for the development of PSS	[1]–[3], [8], [21], [59], [73], [74]
BP24	Adjust the corporate culture, organizational processes and capabilities for PSS	[2], [3], [21], [56], [34]
BP25	Evaluate the Life Cycle Costing of the proposed PSS	[61], [75]
BP26	Implement a holistic systemic dynamic approach for PSS development	[3], [53], [76]
BP27	Develop skills and expertise for integrating a services value stream	[3], [44], [53]
BP28	Evaluate the sustainability performance of the PSS across their entire life cycle	[16], [17], [20]
BP29	Get leadership commitment for PSS implementation	[44]
BP30	Align service strategy with the market conditions and adapt several organizational factors to align them with the service strategy	[70]

The identified practices present a wide range of considerations that a company should take into account for the development of a PSS: business models, establishment and management of complex networks, new service offerings and value propositions, value creation and co-creation processes, mapping and visualization, value-driven communication, customer interaction, data collection, customization strategies, tangible and intangible values, service strategies and servitization, organizational processes and culture, leadership commitment, etc.

The varied range of subjects and knowledge areas highlights the holistic and cross-functional nature of PSS, which may pose certain challenges for companies not used to engaging with such highly augmented design objects.

Only one identified best practices for PSS development clearly incorporates the environmental dimension in their statements (BP28). The lack of environmental considerations into the definition of the identified best practices for PSS development might be one of the determinant reasons for the non-achievement of environmentally sustainable PSS. The integration of those practices in an ecodesign context has, therefore, the potential to overcome this barrier.

5. EcoM2 for PSS development

The integration of the identified best practices for PSS development into the EcoM2 aims to bring the environmental elements into the PSS context, in order to ensure that the developed PSS will actually have improved environmental performance, when compared to traditional products and/or to other PSS solutions that are not designed with environmental issues taken into account.

The approach for the integration of PSS and ecodesign followed in the previous study took ecodesign as the point of departure and proposed the implementation of PSS as a way to ensure higher opportunities for the improvement of the environmental performance of products and services [29]. In this research, a complementary and more proactive approach was taken, which considered the development of environmentally sustainable PSS as a point of departure and customized the EcoM2 evolution levels to fully encompass the development of environmentally sustainable PSS since the early maturity levels.

In this context, the 30 identified best practices for PSS development were classified according to the five EcoM2 evolution levels (table 1), which were customized for the development of environmentally sustainable PSS. The results of the classification are presented in table 4.

Table 4. Classification of the best practices (BP) for PSS development according to the EcoM2 evolution levels and development phase

Code	BP1	BP2	BP3	BP4	BP5	BP6	BP7	BP8	BP9	BP10
Evolution level	2	3	3	2	3	3	1	3	3	3
Reference model	PSP	CDE	IDE	PSP	IDE	IDE	IDE	IDE	IDE	PLA
Code	BP11	BP12	BP13	BP14	BP15	BP16	BP17	BP18	BP19	BP20
Evolution level	3	4	3	4	2	1	1	2	4	5
Reference model	PAM	PAM	CDE	CDE	CDE	PSP	PLA	CMP	PPR	PSP
Code	BP21	BP22	BP23	BP24	BP25	BP26	BP27	BP28	BP29	BP30
Evolution level	3	4	3	2	3	4	2	3	1	5
Reference model	IDE	PLA	IDE	CMP	CDE	CDE	CMP	CDE	CMP	PSP

Furthermore, an analysis of the existing 62 practices of the EcoM2 in light of the identified practices for PSS development resulted in the modification/adaptation of the ecodesign management practices (EMP) (Table 5). Particularly, the practices that addressed solely the development of products were adapted to address PSS development. Although this may appear at a first glance to be little more than a slight change in the wording of the management practice, this alteration brings new challenges and opportunities for companies, broadening their scope and area of influence, and requiring the adoption of another set of tools and methods. Additional effort should be employed by traditional product development companies for the joint development of the products and services, together with the infrastructure and/or ecosystem around the product/service.

Table 5. Ecodesign management practices (EMP) for PSS development

Code	Best practice
EMP1	Structure a systematic procedure to gather ecodesign and PSS-related knowledge
EMP2	Perform internal and external benchmarking of the environmental performance of PSS
EMP3	Examine the relevant internal and external drivers for the development of PSS with better environmental performance
EMP4	Collect information about applicable legal issues and standards related to the environmental performance of PSS
EMP5	Formulate the company environmental policy and/or strategy
EMP6	Deploy and maintain an environmental policy and/or strategy in the PSS levels
EMP7	Establish a prioritized program for the implementation and management of ecodesign
EMP8	Select relevant people from functions across the company to be involved in the ecodesign activities
EMP9	Define and measure performance indicators for the performance of the ecodesign program
EMP10	Increase consciousness and awareness in regards to the application opportunities and benefits of ecodesign and PSS
EMP11	Ensure commitment, support and resources to conduct the activities related to ecodesign
EMP12	Deploy the responsibilities and authorities among people of different areas and hierarchical levels
EMP13	Ensure appropriate communication among departments and different hierarchical levels
EMP14	Select and customize ecodesign methods and tools according to the company's needs
EMP15	Provide ecodesign related training for the employees involved in PSS development and related processes
EMP16	Formulate, update and monitor requirements to comply with environmental PSS-related legislation
EMP17	Implement the Life Cycle Thinking into the PSS development and related processes
EMP18	Evaluate the environmental performance of PSS during the development process
EMP19	Assess technological and market trends (including new customer requirements) related to PSS and ecodesign
EMP20	Identify customers' and stakeholders' requirements and priorities concerning the environmental performance of PSS
EMP21	Develop and customize environmentally product-related guidelines to support PSS development
EMP22	Incorporate environmental aspects in the identification, qualification and management of suppliers
EMP23	Optimize existing production processes to improve the environmental performance of PSS during manufacturing
EMP24	Improve the environmental performance of packaging and distribution during the PSS development
EMP25	Make environmental considerations a part of the daily routine of the employees involved with PSS development
EMP26	Develop a "green" incentive scheme for the ecodesign implementation and management into PSS development
EMP27	Integrate ecodesign into the PSS development and related processes standards and procedures
EMP28	Measure and monitor the environmental feasibility of new PSS development projects
EMP29	Define the environmental indicators and the methodology for the gates (phase assessments)
EMP30	Check the environmental performance of PSS during the phase assessments (gates)

EMP31	Ensure alignment among strategic and operational dimensions concerning ecodesign
EMP32	Establish priorities on the environmental impacts to be minimized over the PSS life cycle
EMP33	Clearly define the goals to improve environmental performance of the PSS under development
EMP34	Include the environmental goals into the PSS target specifications
EMP35	Define and measure environmental performance indicators for PSS improvement
EMP36	Consider the trade-offs among environmental requirements and traditional requirements of a PSS (such as quality and cost)
EMP37	Identify the ecodesign guidelines that can be applied in PSS design in order to increase the environmental performance of the PSS under development
EMP38	Select and develop manufacturing and assembly processes with better environmental performance
EMP39	Identify and/or develop new technologies that can contribute to improve the environmental performance of the developed PSS
EMP40	Evaluate the environmental performance of technologies
EMP41	Define and measure performance indicators for the environmental performance of stakeholders such as suppliers, after sales, service providers, recyclers, etc.
EMP42	Communicate the environmental performance and benefits as part of the total value proposition of the PSS, exploring green marketing opportunities
EMP43	Clearly define the PSS-related environmental goals for the whole company
EMP44	Conduct management reviews to evaluate the effectiveness of the environmental issues consideration in the PSS development and related processes
EMP45	Perform functionality analysis to determine requirements for a PSS and find new ways to deliver the functions with a better environmental performance
EMP46	Improve the interaction between product and service developments in order to explore the potential to offer solutions with a better environmental performance
EMP47	Consider environmental performance as a selection criteria for the PSS concept/design options
EMP48	Consider and involve the total value chain for improving the environmental performance of PSS
EMP49	Establish cooperation programs and joint goals with suppliers and partners aiming to improve the environmental performance of PSS
EMP50	Develop the technical support processes (e.g. maintenance, change of spare parts, etc.) aiming to improve the environmental performance of the PSS over its entire life cycle
EMP51	Define the end-of-life and reverse logistics strategies to be addressed during PSS development
EMP52	Elaborate and communicate recommendations to consumers on how to improve the environmental performance of the PSS during the use and end-of-life phases
EMP53	Communicate to customer and stakeholders the improvements on the PSS environmental performance and consequent economic gains
EMP54	Monitor the PSS environmental performance during use and end-of-life phases of the life cycle
EMP55	Supply the PSS development process with information related to the environmental performance of materials, processes and components in the whole product life cycle phases
EMP56	Effectively integrate PSS-related environmental goals into the corporate strategy
EMP57	Integrate the environmental dimension in the strategic decision making process jointly with the traditional aspects

EMP58	Establish PSS-related vision, strategy and environmental roadmaps in the strategic level
EMP59	Strategically consider the PSS environmental performance in the company portfolio management
EMP60	Develop business, PSS and market strategies considering the environmental trends
EMP61	Incorporate PSS-related environmental goals into the technological strategy
EMP62	Define a strategic roadmap for the development and implementation of new technologies that allows a better environmental performance over the PSS life cycle

In order to enable a harmonization of the ecodesign management practices (EMP) with the identified best practices (BP) for PSS development in the proposed maturity-based approach, a correlation analysis among the ecodesign and PSS practices was carried out. Similar EMP and BP practices were grouped and combined in a consolidated practice that considers PSS development and ecodesign at the same time (Table 6).

Table 6. Harmonization of EMPs and BPs

EMP	**BP**	**Consolidated practice**
EMP11	BP29	Ensure leadership commitment, support and resources to conduct the activities related to ecodesign and PSS
EMP18	BP28	Evaluate the sustainability performance of the PSS across their entire life cycle during the development process
EMP20	P23	Identify customers' and stakeholders' requirements for the PSS and its environmental performance
EMP54	P12	Collect PSS data and environmental performance through increased interaction with customers

By means of the consolidation of the best practices for ecodesign management and PSS development, the resulting EcoM2 for PSS consists of 88 managerial best practices for the development of environmentally sustainable PSS, classified according to five evolution levels and a reference model for product development. The proposed maturity-based approach for the development of environmentally sustainable PSS aims to support the managers responsible for PSS development to define strategic roadmaps for the development of environmentally sustainable PSS, based on a mature and consistent process.

In this context, the *EcoM2 for PSS* can support managers to:

a) Identify strengths and improvement opportunities for sustainable PSS development, based on a diagnosis of the current maturity profile (i.e. capability level of application of the best practices for PSS development). The diagnosis involves a documental analysis and interviews with stakeholders from different functions (e.g. PSS development, manufacturing, marketing, quality, sales, after sales, service, etc.) and hierarchical levels (strategic, tactical and operational). The basic idea is to enable a comprehensive understanding on how PSS is being developed, and how environmental issues are being taken into account.

b) Define the vision and to-be maturity profile, based on strategic drivers and goals towards sustainable PSS development. The ambition level is defined by key strategic managers in the company, which have the formal accountability for managing the development of PSS. The selection of practices to be implemented within a given evolution level is performed based on the strategic drivers and aims of the company, and supported by the analysis of interdependencies among them. In this sense, the model should allow flexibility for the companies to identify what are the most important practices for their context.

c) Deploy a strategic roadmap to integrate PSS and ecodesign practices into the product development process, with the aim to establishing a mature process for the development of sustainable PSS. The gap for implementation is identified based on the comparison between the current maturity profile and the vision for the company. The roadmap is developed based on the BPs relationships and dependencies. Available resources, potential risks, required competencies, expected project complexity and duration are considered for the development and prioritization of the roadmap. The roadmap aims to support the tactical and operational levels in the company (i.e. managers responsible for the development of PSS).

d) Implement and continuously measure the performance of the improved practices. By engaging in subsequent improvement cycles, companies can continuously keep improving their maturity for the development of environmentally sustainable PSS. The implementation phase requires the involvement of a large variety of stakeholders in the company, from different functions and with knowledge regarding the specific issues for PSS implementation. The selection of the key internal stakeholders to be involved depends on the roadmap (practices selected for further implementation) and on the company's organizational structure.

6. Conclusions and final remarks

Product/service-system (PSS) is a promising business approach that has the potential to increase environmental sustainability performance, when compared to traditional products and services. However, PSS is not intrinsically sustainable – several recent studies have shown that the environmental performance of PSS can actually be worse when compared to traditional products.

The hypothesis advocated in this research is that the implementation of ecodesign best practices with best practices for PSS development has the potential to increase the environmental performance of the developed PSS, supporting the transition towards a more environmentally sustainable system and society.

In order to be able to test the hypothesis, this paper presented a proposal for the integration of PSS and ecodesign based on the Ecodesign Maturity Model (EcoM2). The maturity-based approach aims to provide guidance to companies on the selection of practices to be implemented based on their current maturity profile and on the vision towards enhanced profiles with the ultimate goal of developing PSS with improved environmental performance.

In total, thirty best practices for PSS development were identified and consolidated based on a literature review and further integrated into the Ecodesign Maturity Model (EcoM2), through a classification based on the evolution levels and phases for a reference model for product development.

The classification of the best practices for PSS development according to the adapted EcoM2 evolution levels shows that 13 out of 30 BPs should be applied in the evolution level 3, which entails the strong focus of the identified PSS best practices in the actual development phase of PSS and integration into existing development processes and procedures. On the other hand, the classification also highlights the importance of applying the evolution level 1 (with four practices) and evolution level 2 (with six practices) to create the necessary foundation for the development of environmentally sustainable PSS in terms of identifying the drivers for moving to a PSS-oriented business model and implementing change management practices.

The classification of the best practices for PSS development according to the product development phases shows the importance of considering PSS in the early stages of the development process: product strategic planning (PSP), informational design (IDE) and concept design (CDE) embrace 18 out of the 30 identified practices. The classification highlights the strategic nature of PSS, their strong influence in the business strategy, and the importance of close links with customers and stakeholders for value creation. Furthermore, it indicates that the traditional process for product development, especially detailed design (DDE) and production preparation (PPR), suffers limited modifications for PSS development in comparison to product development. On the other hand, product launch (PLA) and product accompanying and monitoring (PAM) seems to play a crucial role in ensuring the business success of the developed PSS. Furthermore, change management practices (CMP) seems to be crucial to enable the company to move from a product-oriented approach to a PSS-oriented approach.

The proposed *EcoM2 for PSS* is a management framework developed to support companies in the integration of environmental considerations into product and PSS development, and has the potential to support companies in the development of environmentally sustainable PSS. The adjusted *EcoM2 for PSS* model presents a total amount of 88 management practices. By combining the best practices for PSS development identified in this research (30 practices), with the existing 62 ecodesign management practices of the EcoM2, this research increases the possibility for companies to develop environmentally improved PSS solutions, when compared to other products and PSS solutions.

Besides being more comprehensive, the addition of practices to the EcoM2 might be cumbersome and make the application by development companies more complex and time consuming. Furthermore, due to the current observed disconnection between PSS and ecodesign implementation, companies might decide to continue focusing on the BPs for PSS development and disregard the ecodesign BPs (and the other way around). Our assumption, that still needs to be tested by industrial application, is that the proposed model can support companies to integrate ecodesign and PSS for the development of environmentally sustainable PSS. Therefore, future research should focus on the test of the applicability and robustness of the proposed *EcoM2 for PSS* model in companies, via action research and industrial case studies for theory testing. Companies with different maturity levels on ecodesign implementation and PSS development, and different strategic drivers, should be targeted in those applications, in order to test if the proposed approach can support PSS practices to evolve towards environmental sustainability. Our underlying assumption is that the availability of a maturity framework can support companies in the transition to the development of PSS with an increased environmental performance.

In addition to contributing to expand the knowledge in the development of environmentally sustainable PSS, this research builds upon previous research to integrate PSS and ecodesign. Currently, a research is being carried out to support the identification and systematization of methods and tools that can support the application of the identified best practices, building up a comprehensive body of knowledge of PSS practices. Furthermore, social best practices are being collected to enable the development of a maturity-based approach that will have a comprehensive sustainability approach, with social, economic and environmental issues.

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